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Impact of pre-monsoon thunderstorm on tropospheric VHF propagation

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Abstract : Thunderstorms which occur during the pre-monsoon season are the most common kind of storms over the eastern region of India Onset and departure of these storms bring large scale changes in the thermodynamic state of the lower atmosphere In this paper, we have studied the impact of these pre-monsoon thunderstorms on tropospheric propagation of 188 MHz TV signal over a 70 km path situated between Satkhira TV station in Bangladesh and Electronics and Communication Science Unit of Indian Statistical Institute, Kolkata (India) The propagation characteristics of 188 MHz TV signal observed on stormy days are compared with those which observed during the normal days of the same season It is observed that these pre-monsoon thundersrorm bring a noticable change in fading characteristics of the 188 MHz VHF signal. In addition to this, SODAR observations and radiosonde data are analysed to study the radioclimatology during these stormy days and obtained results are compared with that observed during the normal days of the same season

Keywords Electromagnetic wave propagation, thunderstorms, troposphere

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1. Introduction

During the pre-monsoon season, the sun reflects vertically on the Tropic of Cancer (22°N latitude) causing a high surface temperature, and a strong convection becomes possible during the day time. Due to the strong vertical air current, the moisturized air rises (height range of 4500 meter to 9000 meter) at the expense of its latent heat of condensation and the cloud formation due to this activity is of the cumulonimbus type. It is a very alarming situation and gives the indication for the occurrence of thundersqualls. Thunderstorms formed by this process have different name in different parts of India. In the eastern part of India, specifically in West Bengal (India) and Bangladesh, it has the name *Kalbaishakhi* or *Nor'westers*. In the northern part of India, these pre-monsoon thunderstorms are called by the name *Andhi* or *Dust-storm*. In the early pre-monsoon season (from the end of February to the end of March) the frequency of occurrence of such phenomena is hardly one or two per month, while during the peak pre-monsoon season (April/May), their number increases from five to fifteen per month. Sometimes they may occur even twice a day.

We have designed an experimental set up to study the impact of these storms on tropospheric radiowave propagation and the corresponding radioclimatology [1,2]. During the course of our experiment and data collection, a number of pre-monsoon thunderstorms hit our place of observation. In these stormy days, we have recorded the VHF signal level carefully so that the actual influence of these stormic activities on tropospheric VHF propagation can be investigated. To study the radioclimatology, we have designed a 2350 Hz monostatic Sound Detection and Ranging (SODAR) system and recorded the observations on a regular basis. In addition to this, we have collected the radiosonde data from the nearby civil-aviation department.

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In this paper, initially we will discuss the impact of Nor'westers on average VHF signal level. The effect of these storms on fading rate and depth of VHF signal will also be discussed in the following sections. In addition, radioclimatic conditions deduced from radiosonde and SODAR observations will be presented in this paper.

2. Description of the experimental set up to record the data

Figure 1 shows the simple block diagram of the experimental set up used to record the VHF signal level. A 188 MHz TV signal is transmitted regularly from Satkhira TV station, Bangladesh from 1630 hours to 2230 hours. VHF signal level has been recorded regularly at the Electronics and Communication Science Unit of Indian Statistical Institute, Kolkata. A highly directional Yagi antenna situated over 30 meter tall geology building of the Institute is used to receive the signal. The transmitted power of antenna is 2 kilowatt. The distance between the transmitting and the receiving antenna is approximately 70 kilometer. The speed of the strip chart recorded was kept at 60 cm/hour. A high frequency signal generator (T801) is used to calibrate the system.

3. Nor'westers : a pre-monsoon seasonal phenomena over the eastern region of India

Over the eastern coastal region of India, thundersqualls are experienced as early as in the month of February. The number of their occurrence gradually increases and reaches a maximum in the month of April and May and decreases considerably thereafter. These thundersqualls occur usually in the afternoon and evening hours but sometimes have been observed at other times of day and night also. A large number of these thundersqualls strike from the northwest direction That is why, sometimes these thunderstorms are also termed Nor'westers. Occasionally, these thunderstorms may arrive from other directions also. These Nor'westers, which are also called Kalbaishakhi, may arrive with a wind speed of 40 to 80 km per hour. Sometimes their speed may exceed 100 km per hour. These-thundersqualls are accompanied by thunder, lightning and rainfall of about 25 mm on an average, but in some cases rainfall may exceed 50 mm or more. These pre-monsoon seasonal storms bring a noticeable change in surface temperature. It has been observed that the average fall in temperature due to these thunderstorms is of the order of 10 to 15°C, whereas in some particular cases, the fall in surface temperature may be of the order of 20°C or above. Finally, it has been observed that the surface pressure increases invariably before the onset of these Nor'westers.

From the upper air measurements by radiosonde technique and other methods, it has been noticed that over the eastern region of India, the first kilometer of the atmosphere remains in a state of instability with a large store of energy. This instability is not always manifested but may exist in a latent state. It requires a further impulse to get released from higher level, sometimes with great violence. This impulse or trigger action is generally provided from natural processes. The most important natural process is intensive solar heating which reaches a maximum during afternoon hours and causes large convectional updraft of air from the lower level to the higher level of the atmosphere. The afternoon and

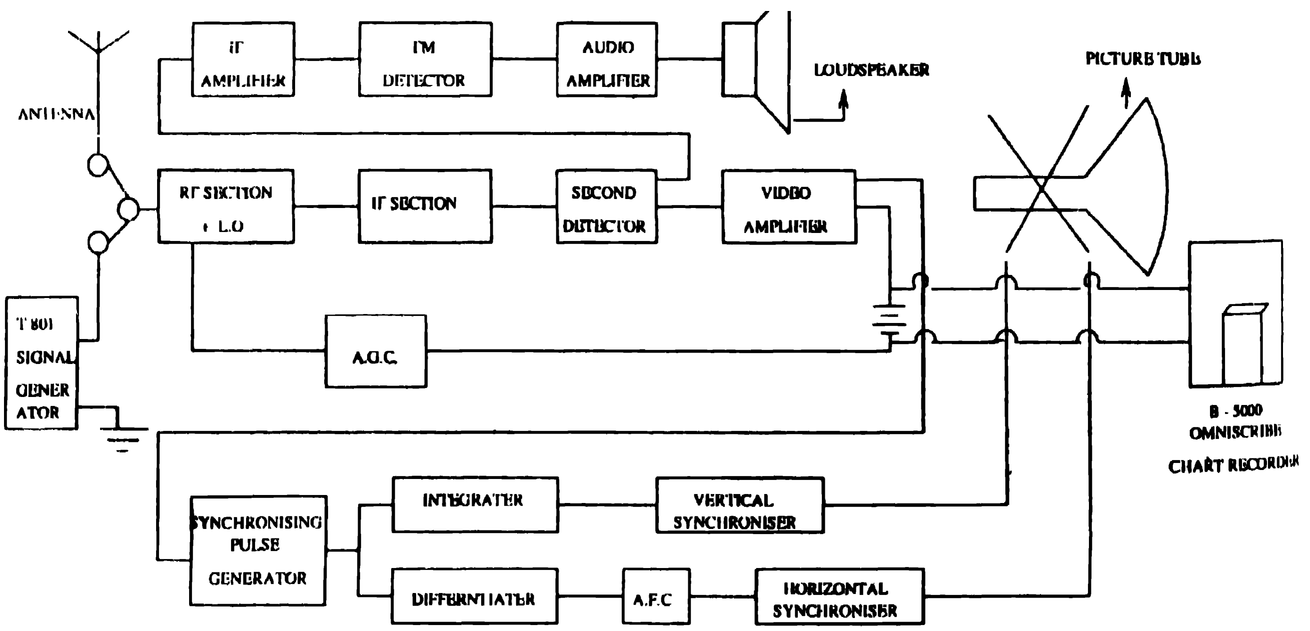

Figure 1. Experimental set up to record the VHF signal level.

early evening thunderstorms are generally formed due to this process. A large amount of energy can be released in the higher level of the atmosphere due to the rising of the air current over either a hill top or a barrier of cold air mass. According to this process, thundersqualls may form at any time during the day and night.

Characteristics and behavior of thunderstorm, duststorm and sandstorm are studied by many scientists all over the world, working in the area of climatology and radiometeorology. They have also studied the impact of these storm on radiowave propagation. Meien [3] studied the formation of inversion layer during the severe storm in Hunan Province. Falconer [4] used radar system to study the behavior of thunderstorm across New York State. Louregz and Ale [5] studied the characteristics of duststorm over Melbourne city in Australia. The transport and spatial scale of Asian duststorm clouds had been studied by Iwasaka *et al* [6]. Kalaki *et al* [7] used ionospheric sounding satellite to study the global distribution of thunderstorm activity. Bader [8] made a simultaneous use of Radar and Rain gauge system to study the behavior of severe thunderstorm near Manchesters Prepgrass and Krider [9] made an attempt to study the phenomena of lightning and surface rain fall during the occurrence of a thunderstorm over Florida. Orgill and Schmel [10] studied the frequency and diurnal variation of duststorm in USA. Ghobrial [11] investigated the effect of sandstorm on microwave propagation.

4. Impact of Nor'westers on average VHF signal level variation

In the previous section, we have discussed the characteristics and behavior of Nor'westers or Kalbaishakhis. In this section, we will discuss the effect of these pre-monsoon seasonal thunderstorms on VHF signal level variation. To visualize this effect, we have recorded the VHF signal carefully during the passage of these seasonal thunderstorms over our site of experiment.

Figure 2 presents the behavior of the average VHF signal level during some days of pre-monsoon season which experienced the occurrence of thunderstorm between afternoon and evening hours. Similarly, Figure 3 describes the behavior of the average VHF signal level during some days of the pre-monsoon season which are free from occurrence of thunderstorm (normal days) between afternoon and evening hours. It can be observed from the Figure 3 that during normal days after the sunset, the average VHF signal level improved continuously with time, whereas Figure 2 shows that on stormy days, the average VHF signal level experienced rapid fluctuations. On 17th April 1986 (curve 1 in Figure 2), we observed the formation of thundercloud around 18 hours, and a thunderstorm with 65 km/hr wind velocity hit our site of observation around 1820 hrs. This thunderstorm has brought about 15.5 db drop in average

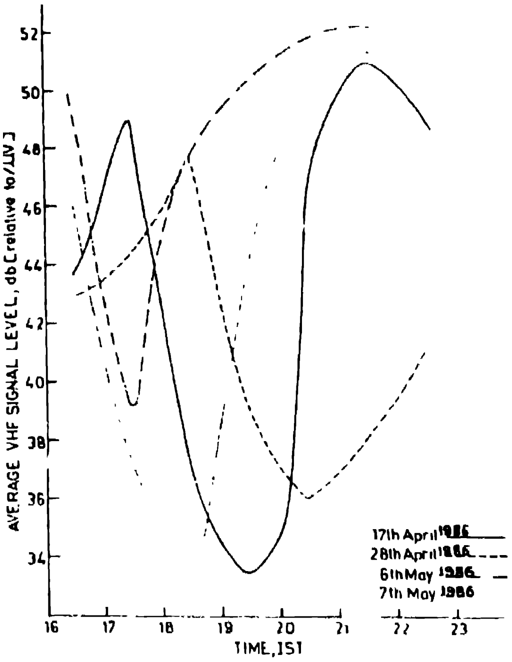

Figure 2. The behavior of the average signal level of 188 MHz TV signal during some days of the pre-monsoon season, experiencing thunderstorm

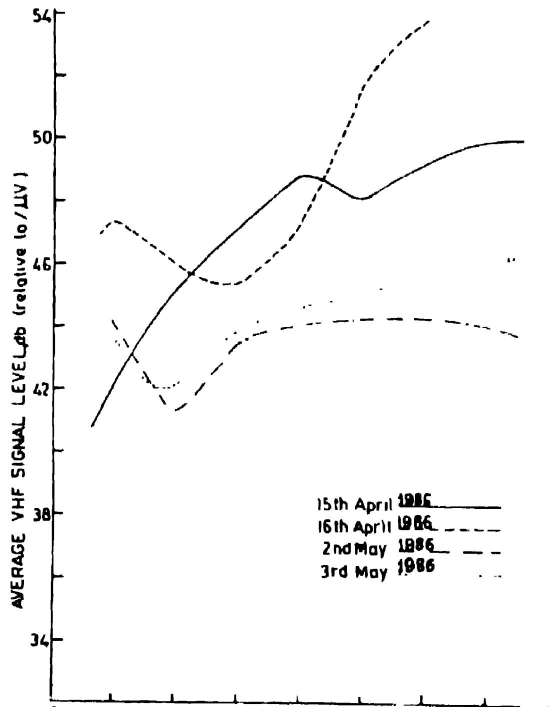

Figure 3. The behavior of average signal level of 188 MHz TV signal during some normal days of the pre-monsoon season.

VHF signal level. At the same time, departure of the thunderstorm enhanced the average VHF signal level by 18.5 db.

Similarly, curves 2, 3 and 4 in Figure 2 represent the behavior of average VHF signal level during 28th April 1986, 6th May 1986 and 7th May 1986 respectively. On 28th April, at about 1957 hours, a thunderstorm with 65 km/hr wind velocity hit the experimental site. Due to the onset of this thunderstorm, VHF signal level experienced about 12 db drop, whereas the dissipation of the thunderstorm brought a significant improvement in average VHF signal level. Similarly, curves 3 and 4 describe that on 6th May and 7th May 1986, due to onset of thunderstorm the average VHF signal level decreased by 10 db and 12 db respectively, whereas departure of thunderstorms was associated with a noticeable improvement in average VHF signal level.

From the above results, it can be concluded that during the normal days of the pre-monsoon season, the average VHF signal level improves during evening hours. On the other hand, during stormy days the average VHF signal level experiences a significant drop (of the order of 10 to 15 db) during the mature stage of the thunderstorm whereas departure of a thunderstorm is generally associated with a remarkable improvement in average VHF signal level. It has also been noticed that most of the time, this improvement persisted for a longer duration of time.

5. Impact of Nor'westers on fading rate of a 188 MHz VHF signal

In this section, we will investigate the impact of Nor'westers on average fade rate of a 188 MHz VHF signal propagating over a 70 kilometer LOS link situated between ISI, Kolkata (India) and Satkhira TV station, Bangladesh.

Figure 4 represents the variation of average fade rate of a VHF signal during some days of the pre-monsoon season

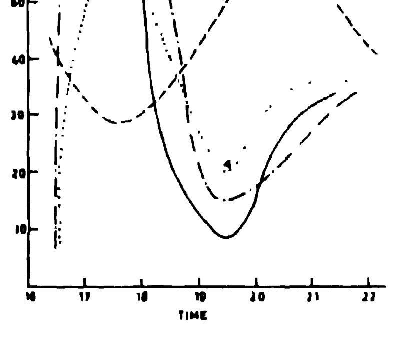

Figure 4. The behavior of average fade rate of 188 MHz VHF signal during some days of the pre-monsoon season, experiencing thunderstorm

which have experienced the occurrence of thunderstorm between afternoon and late evening hours. Similarly, Figure 5 presents the behavior of average fade rate of a VHF signal during some normal days of the pre-monsoon season

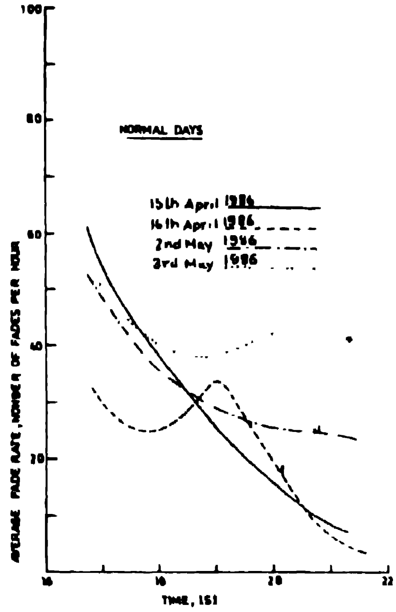

Figure 5. The behavior of average fade rate of 188 MHz VHF signal during some normal days of the pre-monsoon season

(days which are free from occurrence of thunderstorm during afternoon or early evening hours). It can be observed from Figure 5 that during normal days after sunset, the average fading rate decreased slowly with time, whereas on the other hand, Figure 4 shows that during stormy days the average fade rate of a VHF signal experienced a rapid fluctuations.

Figure 4 depicts that on 17th April 1986, due to the onset of a thunderstorm, the average fade rate of a VHF signal reached as high as 80 fades per hour. Afterwards, it started decreasing with the dissipation of the thunderstorm. Curve 2 describes that on 28th April 1986, due to the onset of a thunderstorm at around 1957 hrs IST, the average fade rate of VHF signal increased from 28 fades per hour to 65 fades per hour between 1730 and 2030 hrs IST, whereas the dissipation of a thunderstorm brought about a sharp fall in average fade rate of the VHF signal. Similarly, curves 3 and 4 show that on 6th and 7th May 1986, due to onset of thunderstorm, the average fade rate has increased to 85 and 60 fades per hour respectively. Analogous to the previous cases, here also we can observe a rapid fall in the average fade rate after the departure of the thunderstorm.

From the above experimental results, it can be concluded that the onset of pre-monsoon seasonal thunderstorms brings a sharp increase in average fade rate of a 188 MHz (VHF band) signal, propagating over a 70 km long tropospheric LOS link situated between ISI, Kolkata, and Satkhira TV station, Bangladesh, whereas the average fade rate of the VHF signal always decreases after the dissipation of a thunderstorm.

6. Impact of thunderstorms on the average fade depth of a 188 MHz VHF signal

In this section, we will discuss about the impact of pre-monsoon seasonal thunderstorms on the average fade depth of the same signal, propagating over a tropospheric LOS link situated over the eastern region of India.

Figure 6 describes the behavior of average fade depth of the VHF signal during few stormy days of the pre-monsoon season. Similarly, Figure 7 shows the behavior of the average fade depth of the VHF signal during few normal days of the pre-monsoon season.

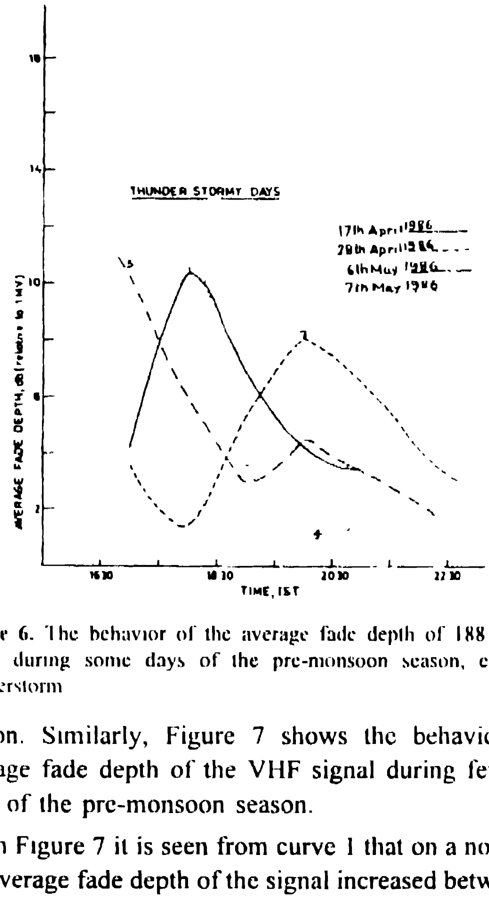

Figure 6. The behavior of the average fade depth of 188 MHz VHF signal during some days of the pre-monsoon season, experiencing thunderstorm

In Figure 7 it is seen from curve 1 that on a normal day, the average fade depth of the signal increased between 1630 and 1830 hrs IST, whereas it decreased during the late evening hours. Curve 2 shows that the average fade depth increased between 1730 and 1930 hrs IST and it decreased between 1930 and 2030 hrs IST, whereas during later hours it remained almost unchanged. Curve 3 depicts that on a normal day, the average fade depth of the signal increased between 1630 and 1730 hrs IST and decreased gradually between 1730 and 1930 hrs IST. During the late evening hours, the average fade depth experienced negligible change with respect to time. Curve 4 shows that the average fade depth increased between 1630 and 1730 hrs IST, and 1830 and 2030 hrs IST respectively, whereas during normal days, change in average fade depth was nearly negligible. So it can be concluded that the average fade depth of a VHF signal has a tendency to increase during early evening hours, whereas its variation with respect to time is negligible during the late evening hours.

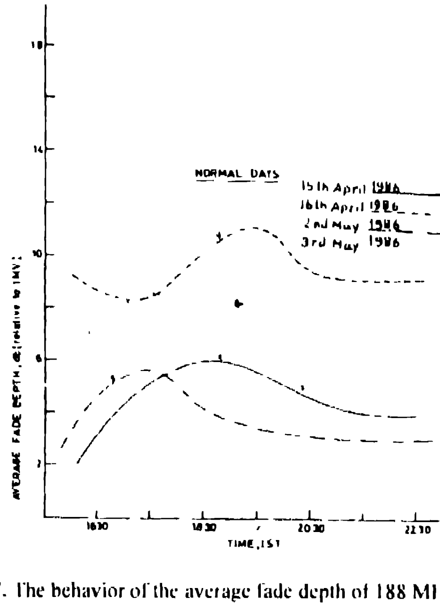

Figure 7. The behavior of the average fade depth of 188 MHz VHF signal during some normal days of the pre-monsoon season

On the other hand, Figure 6 shows that during the stormy days of the pre-monsoon season, the fade depth of the VHF signal rises significantly during the onset of the thunderstorm whereas, departure of thunderstorm is always associated with a sharp fall in the average fade depth. It can be seen further that due to departure of thunderstorm, fall in the average fade depth may be as high as 10 db (as it can be observed from the curve 4 of the Figure 6)

Therefore, from the above experimental results, it can be concluded that the onset of pre-monsoon seasonal thunderstorms brings a sharp increase in the average fade depth of a 188 MHz VHF signal, propagating over a 70 km long tropospheric LOS link situated between ISI, Kolkata, and Satkhira TV station, Bangladesh, whereas the average fade depth of the VHF signal always decreases sharply after the dissipation of a thunderstorm.

7. Radioclimatic condition during thunderstorm days : deduced from radiosonde observations

Radiosonde data, collected from nearby Civil-Aviation department, Dum Dum Air port, Kolkata, has been analyzed to study the radioclimatic conditions during stormy and normal days of the pre-monsoon season over the eastern region of India. It is well known fact that these pre-monsoon thunderstorms are always associated with high wind speed and heavy precipitation, which in turn brings a massive change in the thermodynamic state of the first few kilometers of the lower atmosphere. To study the impact of these changes at surface level, surface data for temperature, pressure and humidity have also been collected from the Indian Meteorological Department, Kolkata. These data are analyzed to study the diurnal variation of radio refractivity at surface level (N_S). Figure 8 describes the diurnal variation in surface refractivity during some normal days of the pre-monsoon season over the eastern region of India. Similarly Figure 9 shows the diurnal variation in surface refractivity during a few stormy days of the pre-monsoon season over the same region.

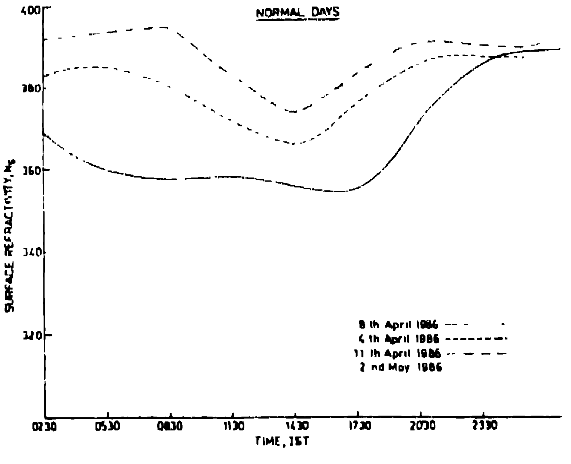

Figure 8. Diurnal variation of surface refractivity during the normal days of the pre-monsoon season

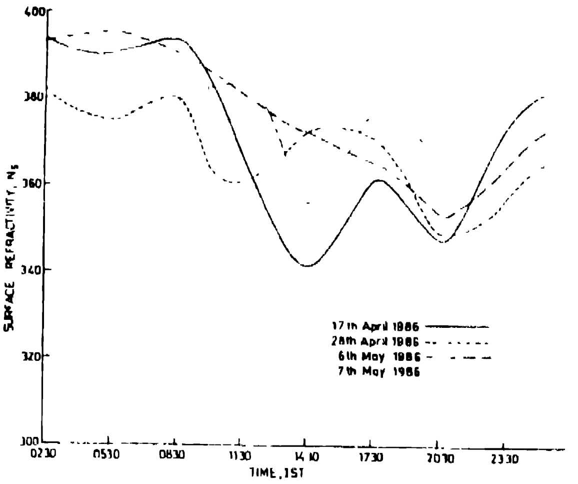

Figure 9. Diurnal variation of surface refractivity during some days of the pre-monsoon season, experiencing thunderstorm.

In Figure 8, curves (1–4) show the diurnal variation in surface refractivity on 8th April 1986, 4th April 1986, 11th April 1986 and 2nd May 1986 respectively. These days are free from the occurrence of thunderstorm. It can be seen from the figure that during the normal days of the pre-monsoon season, the surface refractivity decreased gradually during the afternoon hours (1430 hrs IST). This continuous decrease in surface refractivity takes place due to a rise in surface temperature by day time (due to warming of the earth surface by solar radiation). Between 1430 and 2030 hrs IST, the surface refractivity increased continuously. This continuous increase in surface refractivity takes place due to drop in surface temperature during night time (due to emission of infrared radiation by the earth surface during night time). During late evening hours, the surface refractivity remained almost unchanged. In Figure 9, curves (1–4) show the diurnal variation in surface refractivity on 17th April 1986, 28th April 1986, 6th May 1986 and 7th May 1986 respectively. In these days, the occurrence of thunderstorms took place between 1630 and 2030 hrs IST. There exists a noticeable difference between the diurnal variation of surface refractivity during the normal and the thunderstormy days of the pre-monsoon season. Curve 1 shows that on 17th April the surface refractivity experienced about 50N-units drop between 830 and 1430 hrs IST. Again, it decreased by about 14N-units between 1730 and 2030 hrs IST, whereas it increased by about 20N and 25N-units between 1430 and 1730 hrs IST and between 2030 and 2330 hrs IST respectively. Similarly, on 28th April 1986, the surface refractivity decreased by 20N and 25N-units between 830 and 1130 and between 1430 and 2030 hrs IST respectively, whereas it increased by about 10.5N-units between 1130 and 1430 hrs IST, and by about 10N-units between 2030 and 2330 hrs IST. On 6th May 1986 (curve 3) the drop in surface refractivity was observed till 2030 hrs IST. Afterwards, it increased continuously. Curve 4 shows that on 7th May, 1986 the surface refractivity increased by 25.5N and 11N units between 1130 and 1430 hrs IST and between 1730 and 2030 hrs IST respectively. On the other hand, it increased by 22N and 13N-units between 1430 and 1730 hrs IST and between 2030 and 2330 hrs IST respectively.

Table 1. Radiorefractivity gradients at different pressure level before the occurrence of the thunderstorm

Date	Refractivity gradient with respect to earth surface			
	at 950 mb	at 900 mb	at 850 mb	at 800 mb
17 4.86	–2 09	–23.27	–32 98	–36.56
21.4 86	–31.09	–42.56	–49 50	-51 59
22.4.86	–41.42	–34.31	–35 21	37.33

It is observed that the diurnal behavior of the surface refractivity is fluctuating in nature during the thunderstormy days of the pre-monsoon season. At the same time, it has a tendency to decrease during the late evening hours (after 2030 hrs IST), whereas on normal days of the pre-monsoon season, the diurnal variation in surface refractivity has a tendency to decrease continuously with time between 0230 and 1430 hrs IST, and to increase slowly with time between 1430 and 2330 hrs IST.

Figure 10 describes the radio-refractivity profile before the onset of a thunderstorm. On 5th April 1986, 17th April 1986, 21st April 1986 and 22nd April 1986, thunderstorms occurred at 1800 hrs IST, 1845 hrs IST, 2015 hrs IST and 2040 hrs IST respectively. Radiosonde observations recorded at Dum Dum Airport, Kolkata at 1730 hrs IST are analyzed to estimate the radio-refractivity gradients (ΔN) at different pressure levels (or heights). Radiorefractivity gradients estimated at 1730 hrs IST for these dates are presented separately in Table 1. This table indicates that before the occurrence of a thunderstorm, the radio-refractivity gradients (with respect to the surface) at different pressure levels are lying between the sub-refractive ($0 > \Delta N < -40$) and normal refractive range ($-40 > \Delta N > -75$). Similarly Figure 11 describes the radio-refractivity profile after the departure of a thunderstorm. On 6th May 1986, 17th May 1986, 30th May 1986 and 31th May 1986 thunderstorms occurred at 1600 hrs IST, 1245 hrs IST, 1215 hrs IST and 1540 hrs IST respectively. Radiosonde data, recorded at 1730 IST are analysed to study the radio-refractivity gradients at different pressure levels, after the departure of thunderstorm. Table 2 represents the radio-refractivity gradients at different pressure levels, after the departure of the thunderstorm. It can be observed from this table, that after the departure of the thunderstorm, the first few kilometers above the earth surface are highly super-refractive with respect to surface level. It can be noticed further that the values of radio-refractivity gradients at different pressure levels are lying between the normal and super-refractive range.

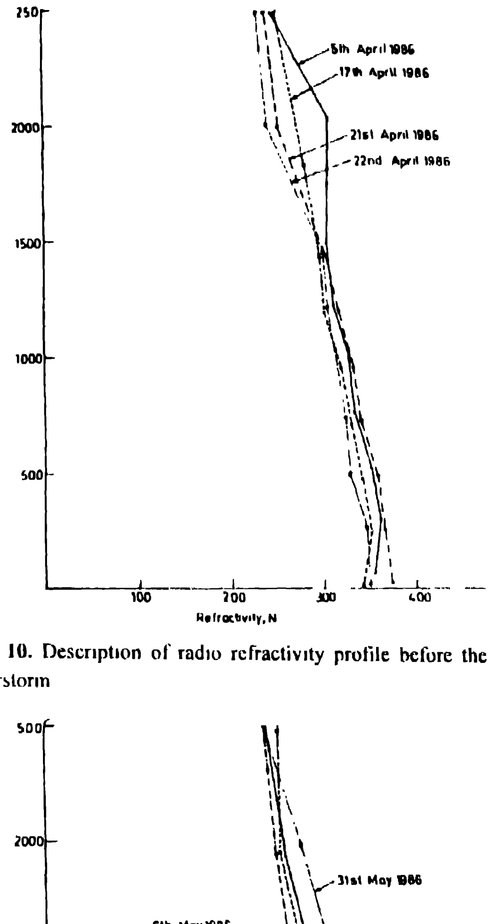

Figure 10. Description of radio refractivity profile before the onset of thunderstorm

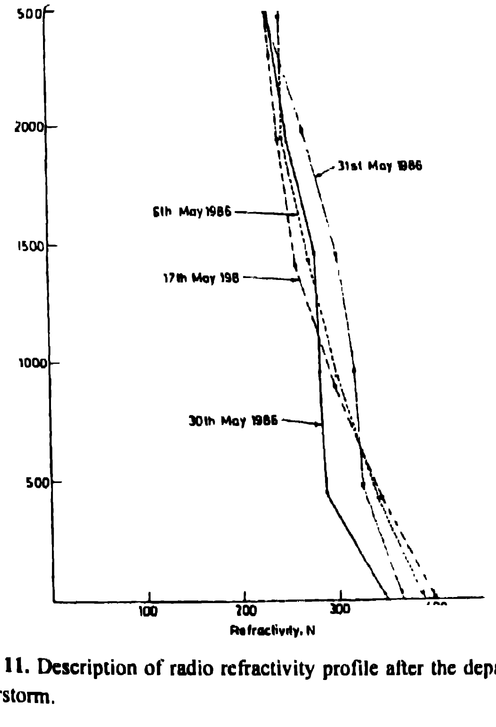

Figure 11. Description of radio refractivity profile after the departure of thunderstorm.

Table 2. Refractivity gradients at different pressure level, after the departure of the thunderstorm.

Date	Refractivity gramdient with respect to earth surface				
	at 950 mb	at 900 mb	at 850 mb	at 800 mb	at 750 mb
6 5 86	−118.87	-93.46	−66 12	−52.66	−46.79
17 5.86	−141 96	−114 58	−100.44	−82 62	−73.49
30.5 86	−134 43	−69 36	−50 16	−50.92	−47 53
31 5 86	−78 21	−47 08	−44.30	−49.61	−54 63

8. SODAR observation of LPBL during some days, experienced thunderstorm

Acoustic radar data are recorded to study the lower atmospheric structures arising due to the occurrence of thunderstorms during the pre-monsoon season over eastern region of India. Environmental noise, produced due to gustiness of wind, restrict the availability of sodar data during the initial stage of thunderstorm. After dissipation of heavy downpour due to formation of anvil shaped cumulonimbus cloud, various types of multilayered structures, associated with wave motion in elevated and ground based inversion layers were recorded. To this section, we will discuss about the acoustic radar observations, recorded during few stormy days of the pre-monsoon season.

Figure 12 : On 26th April 1986, a Nor'wester with 50 km/hr wind speed hit our site of experiment. Black continuous patch from 2228 hours to 2326 hours indicates heavy shower due to outburst of thundercloud formed over the site which brought about an 8°C drop in surface temperature. After departure of heavy shower, information brought by echo pattern appeared as a wave motion in ground-based and

elevated temperature inversion layers. Multilayered structures are formed just before the onset of second shower. During later hours, a thin ground-based temperature inversion layer has been formed.

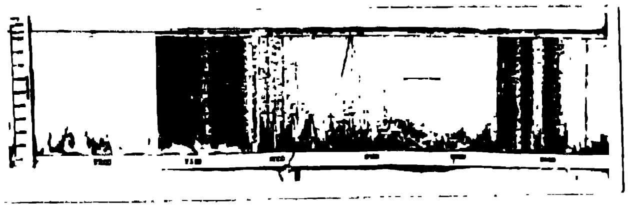

Figure 12. Monostatic SODAR record of thunderstorm on 26th April 1986.

Figure 13 It presents the structure developed on 28th April 1986 after passage of a Nor'wester associated with 65 km/hr wind speed and scattered rain. Due to this thunderstorm, the ground level attained 2°C drop in temperature. Ground-based temperature inversion layer, is formed due to emission of infrared radiation by earth surface. It had experienced a number of frontal disturbances starting from midnight to early morning hours. Passage of these frontal disturbances over the layer of inverted lapse rate had created enormous wind shearing. Impact of wind shear (associated with rapidly changing wind speed and direction) is extremely pronounced on the top of the ground based temperature inversion layer.

Figure 13. Monostatic SODAR record of thunderstorm on 28th April 1986

Figure 14 : It presents a lower atmospheric view obtained after offset of a thunderstormic activity that occurred on 6th May 1986. The thunderstorm was associated with a wind speed of 82 km/hr and 30 mm of rain, which brought about 11°C drop in surface temperature. Due to power failure, we could not record the acoustic radar observations appeared after the departure of heavy shower caused due to thunderstorm. This figure shows that the height of the ground-based temperature layer was raised upto 400 meter (around 2100 hours) due to rapid radiative cooling of the earth surface. Afterwards, from 2200 hours to 0130 hours IST, the Lower Planetary Boundary Layer appeared as a highly turbulent layer associated with multilayered structures and small-scale irregularities clustered around 400 meter level of the lower atmosphere, whereas the thickness of the ground-based temperature inversion layer was 150 meter only.

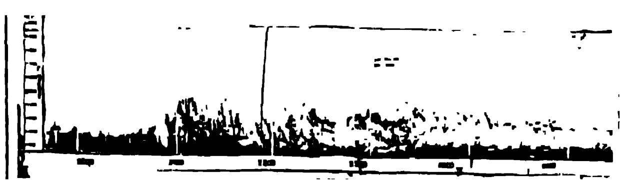

Figure 14. Monostatic SODAR recrod of thunderstorm on 6th May 1986

Figure 15 : This particular structure was obtained on 7th May 1986, after departure of highly gusty wind and scattered rain occurred due to Nor'westers. Due to this Nor'wester surface temperature dropped by 2°C. A broken elevated layer was formed at the height level of 400 meter. The region below this layer revealed the descent of many other elevated layers of small thickness towards the ground. The clear region between these layers indicates the existence of homogeneous atmosphere. Around 0400 hrs IST, the broken elevated layer coalesced with the ground-based inversion layer to form a single layer of 350 meter thickness. During early morning hours (from 0400 hours), as elevated inversion layer associated with wave motion was appeared. These undulating structures, having about 100 meter peak to peak amplitude and slightly disturbed periodicity, sustained for a long time.

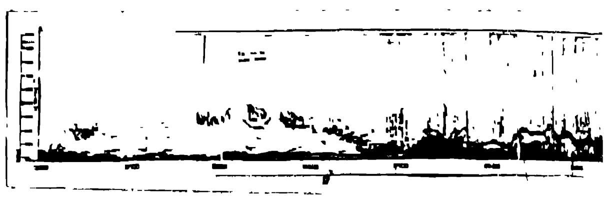

Figure 15. Monostatic SODAR record of thunderstorm on 7th May 1986

Figure 16 : On 13th May 1986, a Nor'wester with 74 km/hr wind speed occurred at our site of experiment. 13.6 mm of rain caused due to this thunderstorm brought about a 7.6°C drop in surface temperature. After the dissipation of heavy downpour due to the thunderstorm, the surface-based layer encountered undulations (wave-like structures). These wave-like structures remained present upto midnight

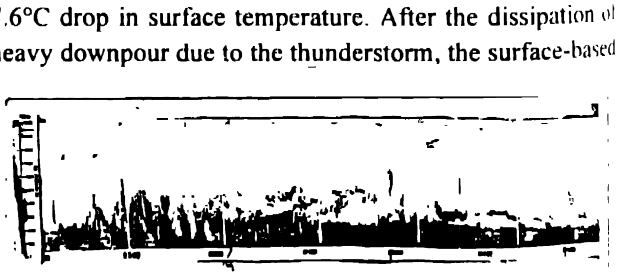

Figure 16. Monostatic SODAR record of thunderstorm on 13th May 1986

Afterwards, small-scale eddies (air masses having different temperature and density structures than that of the surroundings) were seen to exist at about a height of 600 meters (0200 hrs IST). A well-mixed type of atmosphere found about 600 meters. During early morning hours, small-scale eddies of comparatively bigger dimension began to settle on the top of the ground-based inversion layer of 300 meter thickness. From the above experimental observations, it is concluded that departure of pre-monsoon seasonal thunderstorms initiates the formation of wave-motion and multilayered structures in the lower planetary boundary layer

9. Discussion and conclusion

The pre-monsoon seasonal thunderstorms affect the propagation of a 188 MHz VHF signal, propagating over a 70 km long LOS link (situated over eastern region of India) in different ways. We have attempted to study the impact of these seasonal thunderstorms on various parameters such as average VHF signal level, fade rate and fade depth of VHF signal, *etc*. In addition to this, radiosonde data and SODAR observations are also analysed to investigate the effect of these thunderstorms on the radioclimatology of the environment through which the 188 MHz VHF signal is propagating. The following conclusions are drawn from the analysis of recorded data.

1. Due to onset of thunderstorm, the 188 MHz VHF signal experiences about 10 to 15 db loss in its average signal level.
2. Departure to thunderstorms has brought a remarkable improvement in the average level of the VHF signal.
3. Average fade rate of the VHF signal has increased sharply during the mature stage of the thunderstorm.
4. Dissipation of thunderstorm has brought a noticeable drop in the average fade rate of the VHF signal.
5. A significant rise in average fade depth of the VHF signal has been observed during the occurrence of thunderstorm.
6. Departure of thunderstorms has always brought a sharp fall in the average fade depth of the signal.
7. During stormy days, the diurnal variation of surface refractivity has showed an oscillatory behavior, whereas on normal days, the surface refractivity has decreased gradually between 0230 and 1430 hrs IST, and it has increased slowly between 1430 and 2030 hrs IST.
8. Before the onset of a thunderstorm, the refractivity gradients (with respect to the surface level) at different pressure levels (from 950 mb to 750 mb) remained between the normally refractive and sub-refractive ranges.
9. After the dissipation of the thunderstorm, the refractivity gradients at different pressure levels (from 950 m' 'o 750 mb) have remained between the normal a..d super-refractive ranges.
10. Sodar observations reveal that after the dissipation of heavy downpour due to thunderstorm, various types of multilayered structures, sometimes associated with wave-like structure in elevated and ground-based inversion layer are formed in the first few hundred meters of the lower atmosphere.

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